Mutual Interference of Pheromone Traps Within Trap Lines on Captures of Boll Weevils (Coleoptera: Curculionidae)

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ABSTRACT Traps baited with the synthetic aggregation pheromone of the boll weevil (*Anthonomus grandis* Boheman) are often used to monitor population fluctuations, distribution, and behavior. However, many factors generate variability in daily captures, making interpretation of trapping data difficult. Previous studies have shown that wind speed in the microenvironment around a trap can greatly affect numbers captured on a given day. It is possible that variation in air movement may also generate variation in trap captures through its effects on the pheromone plume. The current study was conducted to determine whether five traps placed in a line at two commonly used spacings (15 and 20 m) interfere with one another. There was no evidence for interference on days when winds struck the trap line at a nearly perpendicular angle. However, for both spacings, there were significant and substantial effects of relative trap placement within a line on days when winds struck it at an angle (>22.5°) away from the perpendicular. The largest and most consistent effect was that the trap furthest upwind in the line captured the most weevils, especially on days of moderate wind speeds (10–20 km/h). The upwind trap captured 1.5–2.0 times as many weevils as the next trap in the line, which usually had the lowest percentage of capture of any of the traps. Until the minimum adequate spacing has been established, traps should be placed at least 30 m apart in experiments in which such biases can adversely affect interpretation of results.

KEY WORDS boll weevil, *Anthonomus grandis*, pheromone traps, sampling, wind, flight behavior

THE BOLL WEEVIL (*Anthonomus grandis* Boheman) is a chronic and often severe pest of cotton in areas of the southern United States from which it has not yet been eradicated. Pesticide treatments are most efficient when application decisions are based on population levels within individual fields. Infestation levels are commonly estimated from samples of damaged fruit (Pieters and Sterling 1973, Herzog and Lambert 1984), while adult population densities can be estimated from in-field samples taken by visual inspection, sweep net, beat net, drop cloth, or pneumatic devices (McCoy and Lloyd 1975, Leggett and Roach 1981, Spurgeon and Raulston 1997, Beerwinkle and Coppedge 1998, Raulston et al. 1998). Samples from traps baited with the synthetic aggregation pheromone of the boll weevil are far more convenient to obtain than by any of the techniques mentioned above, but high variability in trap captures from day to day and among traps within days has thwarted efforts to correlate sample numbers to population densities in specific fields. Despite this limitation, pheromone traps are heavily relied upon to detect and monitor populations and potential problem fields, and to guide treatment decisions (Ridgway and Inscoe 1996, Hardee and Mitchell 1997, Smith 1998).

To improve the utility of boll weevil pheromone traps as a tool for monitoring local boll weevil populations, we are attempting to identify and quantify common sources of daily and positional variation in trap captures. Understanding the factors causing fluctuations in weevil captures will permit us to increase the signal:noise ratio in the data through development of better strategies of trap deployment and interpretation of sampling information. We found that wind speed exerts a strong negative influence on captures of boll weevils in pheromone traps, probably through its physical impact on the ability of the weak-flying weevils to approach a trap (Sappington and Spurgeon 2000). Thus, daily variation in weevil captures can be generated by daily variation in synoptic wind speed. Furthermore, local vegetational features can moderate airflow so that traps on the lee side of a windbreak experience lower wind speeds than nearby traps on the windward side, and consequently tend to capture several-fold more weevils (Sappington and Spurgeon 2000). Therefore, substantial positional variation in weevil captures can be generated by variation in wind speed in the microenvironments of individual traps, which in turn is superimposed upon daily variation generated by synoptic wind speeds. The magnitude and patterns of positional effects exhibited on a given day depend not only on synoptic wind speed, but also on synoptic wind direction in relation to potential windbreaks.

In addition to its physical effects on weevil flight, air movement may generate variation in trap captures through its effects on the pheromone plume. Depending on wind direction and distance between traps, the pheromone plumes may overlap to varying extents, potentially affecting the pattern of captures among them (McClendon et al. 1976). Our goal in this study was to determine whether variation in captures of boll weevils is generated among pheromone traps in a line, placed at two commonly used spacings (15 and 20 m), simply by virtue of their proximity to one another. Because the mechanism of such interference presumably involves overlapping pheromone plumes, we reasoned that wind direction and wind speed could influence the form and magnitude of intertrap interference. Thus, we included wind parameters in the analyses.

Materials and Methods

Three sets of boll weevil pheromone trap data were generated from 1998 to 2001, distinguished by trap line orientation and spacing between traps. All trap lines were located along a brush line at the edge of cotton or fallow (depending on the season) fields in Cameron County, TX, in the subtropical Lower Rio Grande Valley. Each trap line consisted of five Hercon Scout boll weevil pheromone traps (Hercon Environmental, Emigsville, PA) mounted on 1-m poles. Each trap was baited with a 10-mg Hercon pheromone lure that was replaced weekly. Traps were monitored daily, except weekends and holidays, or when muddy conditions prevented access to the sites. Multiple-day captures were not included in the analyses. Traps were serviced before 0930 hours each day, and because few boll weevils are captured before 1000 hours (Guerra 1983), we assumed that weevils removed from traps by 0930 hours were captured the previous day.

In the first test, traps were spaced 15-m apart in each of 12 trap lines, which were oriented along predominantly east-west or northeast-southwest axes. Trap lines were positioned in pairs across brush lines, with the closest traps in the respective lines separated by 30 m (see Sappington and Spurgeon 2000 for details). Traps were monitored from 15 December, 1998 through 19 March, 1999. In the second and third tests, six trap lines were positioned along north-south axes. The second test was conducted from 4 June, 1999 through 7 January, 2000, and had traps spaced at 15-m intervals. The third test was conducted from 26 October, 2000 through 27 July, 2001 with trap lines in the same locations as in the second test, but with traps spaced at 20-m intervals. Trap lines were not paired, and the nearest neighboring trap line was always >100 m distant.

A weather station (Campbell Scientific, Logan, UT) was located within 4 km of all trap lines, and measured temperature, wind speed, and wind direction at 2.5 m above the ground every 5 min. Output was generated every 15 min, and consisted of an average of the previous three 5-min readings. Wind direction was corrected for each trap line in the first test according to the latter's deviation from a true east-west orientation, so that the designated 0–180° axis was always perpendicular to the trap line axis. The trap lines in the second and third tests were all oriented close to a true north-south axis, making corrections unnecessary. Daily wind speed and wind direction were obtained by averaging all 15-min readings from 10:00 to sunset, except those time intervals in which the temperature was <15°C, the approximate lower threshold for boll weevil flight activity (Fenton and Dunnam 1928, Gaines 1932, Jones and Sterling 1979).

Data Analysis. All analyses were performed with Statistix software (Analytical Software 1998). Mean daily wind speed was classified as light (<10 km/h), moderate (10–20 km/h), or strong (>20 km/h) (Sappington and Spurgeon 2000). Each trap line was classified daily as being on the leeward or windward side of its brush line, depending on average wind direction for that day. Traps at the end of a line were designated daily as either furthest upwind or furthest downwind, depending on mean wind direction. However, if mean wind direction was within 22.5° of perpendicular to the axis of the trap line, winds were considered to be perpendicular to the line, and no upwind-downwind designation was made.

The number of boll weevils captured in each trap was converted to a percentage of the total capture in that trap line on that day, so that days of high captures could be pooled with days of low captures for analysis. The Kruskal-Wallis (K-W) one-way nonparametric analysis of variance (Kruskal and Wallis 1952, Daniel 1990) was used to detect an effect of trap position within a line on mean percentage of trap capture. If this test indicated a significant effect ($\alpha = 0.05$), significant differences among the traps were determined with the Kruskal-Wallis comparison of mean ranks test (Daniel 1990). Differences in mean percentage of capture (square root, arcsine transformed; Fry 1993) at a trap position in a trap line caused by windward or leeward placement of the lines were analyzed by *t*-tests.

Results

Patterns of differential captures of boll weevils within trap lines were not substantially affected by their placement on either the windward or leeward side of brush lines for any year or spacing (data not shown). Direct comparisons of captures by position for the three data sets provided no evidence for an effect of windward or leeward placement (two-sample *t*-tests, all $P > 0.30$). Therefore, leeward and windward data were pooled for subsequent analyses.

On days when wind was striking pheromone trap lines at an angle >22.5°, there was a significant effect of relative trap position within a line of five traps spaced 15 m apart on the percentage of boll weevils captured in 1998–99, when the trap lines were oriented east-west (K-W statistic = 44.98, $N = 426$, $P <$

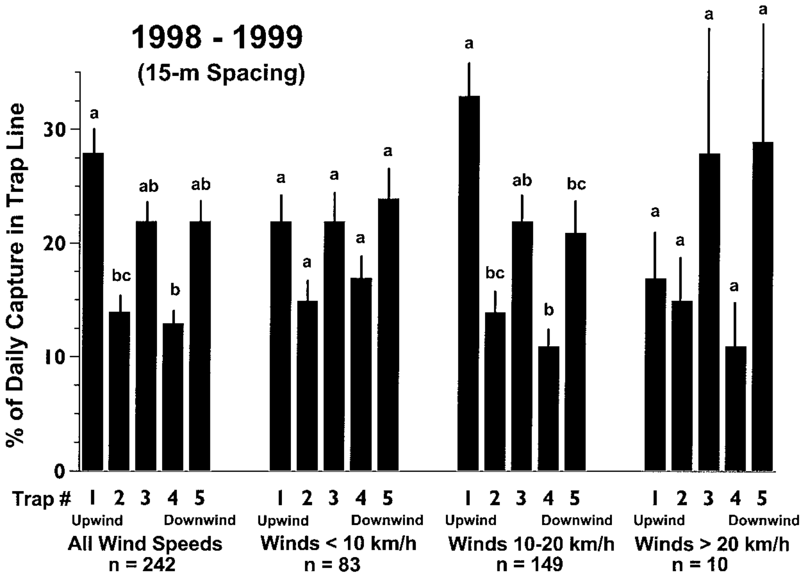

Fig. 1. Mean percentage (+ standard error [SE]) of distribution of boll weevil captures among traps in east-west trap lines at 15-m spacing, 1998–99. Trap 1 indicates the trap furthest upwind in the trap line, while trap 5 indicates the trap furthest downwind. Data from days when average wind direction was within 22.5° of perpendicular to the trap line axis were excluded from the analyses. Means accompanied by the same letter for a given wind speed category are not significantly different (Kruskal-Wallis test; $\alpha = 0.05$). n, Indicates the number of trap line observations under the specified wind speeds.

0.0001), and in 1999–2000, when the trap lines were oriented north-south (K-W statistic = 55.55, $N = 473$, $P < 0.0001$). In 1998–99, the trap furthest upwind captured a significantly higher percentage of weevils than either the second or fourth trap in the line (Fig. 1). This trend was evident on days of light, moderate, and strong winds, but there were significant differences only on days of moderate winds. On these latter days, the trap furthest upwind captured a significantly higher percentage of weevils than all other traps, except the third in line (Fig. 1). In 1999–2000, the trap furthest upwind captured a significantly higher percentage of weevils than any other trap in the line (Fig. 2). When broken down by wind speed category, the highest percentage of capture was always made by the furthest upwind trap. On days of light winds, it was significantly higher than only the last trap (furthest downwind) in the line, and on days with strong winds, it was significantly higher than the second trap only. On days of moderate winds, the trap furthest upwind captured a significantly higher percentage of weevils than all but the last trap in the line, while the trap immediately downwind of the first trap caught significantly fewer weevils than all but the fourth trap in the line. In contrast, on days when winds struck the trap lines within 22.5° of perpendicular, there were no significant differences in percentage of capture of boll weevils based on relative trap position for either 1998–99 (K-W statistic = 6.49, $N = 52$, $P = 0.17$) or 1999–2000 (K-W statistic = 6.60, $N = 114$, $P = 0.16$) (Fig. 3).

When the spacing between pheromone traps in the line was increased to 20 m, there was still a significant effect of relative trap position on weevil capture (K-W statistic = 47.88, $N = 356$, $P < 0.0001$). The trap furthest upwind captured a significantly higher percentage of weevils than any other traps in the line (Fig. 4). The trap furthest downwind captured a significantly higher percentage of weevils than the trap second furthest upwind. When broken down by wind speed category, the furthest upwind trap always captured a significantly higher percentage of weevils than the second trap in the line. On days of moderate winds, the first trap also captured significantly more weevils than the third and fourth traps. On days with winds striking the trap line perpendicularly, there was no significant effect of relative trap position on percentage of weevils captured, but the sample size was small (Fig. 3).

Discussion

Our data clearly indicate an effect of relative position within a pheromone trap line on the percentage of boll weevils captured when traps are spaced 15 or 20 m apart. The most consistent effect was that the trap furthest upwind captures a significantly higher proportion of weevils than some or all of the other traps in the line. The largest differential was usually that between the furthest upwind trap and the next trap in the line, in which the former averaged between 1.5 and 2.0 times more weevils captured than the latter when all wind speeds were pooled. Average differences from 1.6- to 2.4-fold were observed on days of moderate wind speeds.

The mechanism giving rise to these differential captures is unknown. Boll weevils are weak fliers, and probably cannot make direct headway against winds

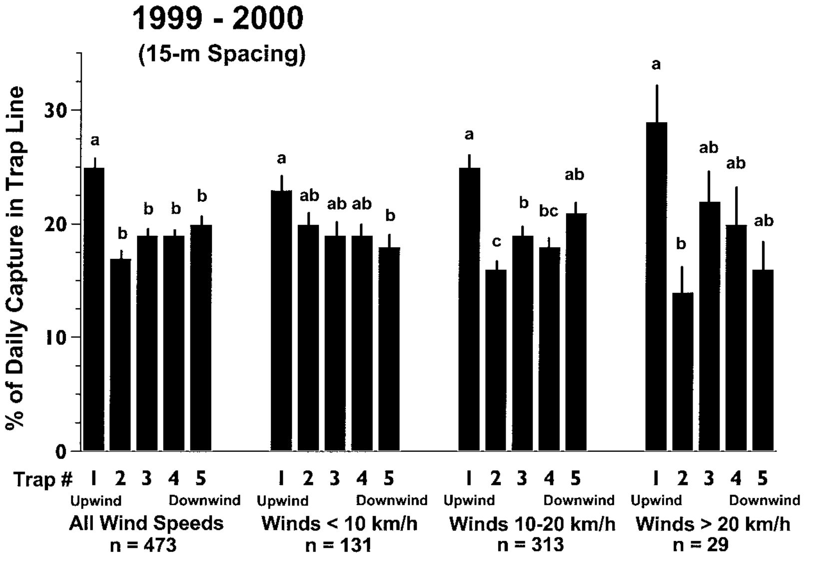

Fig. 2. Mean percentage (+ SE) of distribution of boll weevil captures among traps in north-south trap lines at 15-m spacing, 1999–2000. Trap 1 indicates the trap furthest upwind in the trap line, while trap 5 indicates the trap furthest downwind. Data from days when average wind direction was within 22.5° of perpendicular to the trap line axis were excluded from the analyses. Means accompanied by the same letter for a given wind speed category are not significantly different (Kruskal-Wallis test; $\alpha = 0.05$). n, Indicates the number of trap line observations under the specified wind speeds.

>5–7 km/h (Hardee et al. 1969, McKibben et al. 1991), although they may be able to approach a trap in stronger winds by flying low to the ground in which air speed is lower or by taking a zig-zag course. A weevil flying with the wind and originating somewhere upwind of a trap line would first enter the plume of the trap furthest upwind, and might therefore be more likely to approach that trap. If this is the primary factor generating the observed pattern, then much greater intervals between traps than those tested may be required to eliminate the effect, because it is a mechanism that is not related to plume overlap. However, the lack of a pattern on days of perpendicular winds argues against this mechanism, because one would

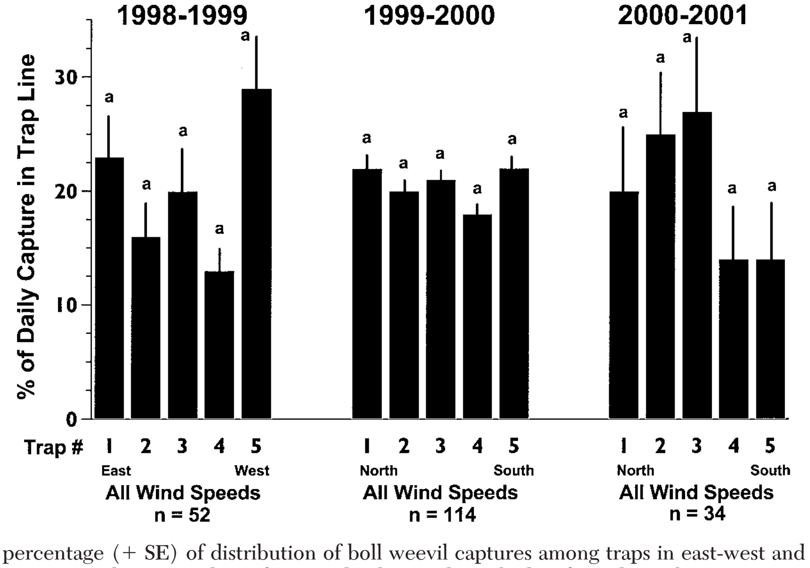

Fig. 3. Mean percentage (+ SE) of distribution of boll weevil captures among traps in east-west and north-south trap lines at indicated spacings and years on days of perpendicular winds. Only data from days when average wind direction was within 22.5° of perpendicular to the trap line axis were included in the analyses. Traps were not designated as upwind or downwind, so trap 1 indicates the trap furthest east or north in the trap line, while trap 5 indicates the trap furthest west or south. Means accompanied by the same letter for a given wind speed category are not significantly different (Kruskal-Wallis test; $\alpha = 0.05$). n, Indicates the number of trap line observations under the specified wind speeds.

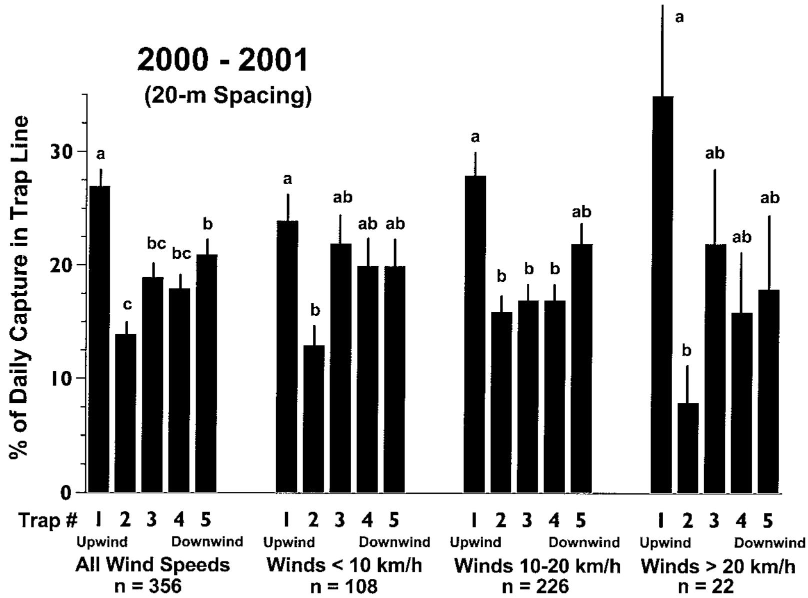

Fig. 4. Mean percentage (+ SE) of distribution of boll weevil captures among traps in north-south trap lines at 20-m spacing, 2000–01. Trap 1 indicates the trap furthest upwind in the trap line, while trap 5 indicates the trap furthest downwind. Data from days when average wind direction was within 22.5° of perpendicular to the trap line axis were excluded from the analyses. Means accompanied by the same letter for a given wind speed category are not significantly different (Kruskal-Wallis test; $\alpha = 0.05$). n, Indicates the number of trap line observations under the specified wind speeds.

expect more chance first encounters with plumes from the outermost traps. In the data set with the largest sample size (1999–2000), captures on days of perpendicular winds were fairly evenly distributed across all five traps.

All trap lines were placed along brush lines, which can affect wind speed (Slosser et al. 1984, Sappington and Spurgeon 2000), and consequently total numbers of boll weevils captured (Sappington and Spurgeon 2000). Brush lines may also affect wind direction on the leeward side through increased turbulence and sheer effects (Lewis and Dibley 1970), which could affect the characteristics of the pheromone plumes of traps located there. However, pheromone plumes leaving traps on the windward side of a brush line presumably pass through the brush and are exposed to the same turbulence as those leaving traps on the leeward side. Thus, it seems likely that however the plumes are affected, they are affected similarly regardless of whether they originate on the leeward or windward side of a brush line. Our data are consistent with this supposition in that windward or leeward placement had no detectable influence on the distribution of boll weevil captures among traps in trap lines.

If captures among traps placed at high density are to be averaged or totaled (e.g., Merkl and McCoy 1978, Sappington and Spurgeon 2000), or if the traps are being used as a direct means of boll weevil control (e.g., Hardee et al. 1970, Boyd et al. 1973, Mitchell et al. 1976, 1977) or collection (e.g., Haynes 1987), then understanding this kind of intertrap variation is important only if it is desirable to optimize the number of traps deployed. McClendon et al. (1976) developed a computer simulation model to predict trapping efficiency and optimal trap spacing for boll weevil removal from a field, but for the sake of simplicity had to incorporate the assumption that traps do not interfere with each other.

When captures in individual traps are used to provide information on boll weevil distribution or dispersal behavior (e.g., Rummel et al. 1980, Carroll and Rummel 1985), it becomes important to avoid artifactual effects of intertrap interference, which could lead to difficulties in interpreting results. Similarly, when traps of different designs are to be compared for efficiency in attracting and capturing boll weevils (e.g., Mitchell et al. 1978, Dickerson et al. 1981, Hardee et al. 1996), or when pheromone formulations and dispensers are compared (e.g., Hardee et al. 1972, Leonhardt et al. 1990), it is desirable to place them as near as possible to one another to ensure that they are sampling from the same area and the same subpopulation of weevils. However, if positional variation is generated from intertrap interference, then traps placed too close together may yield spurious results. Although proper experimental design, such as rotating traps representing different treatments, can alleviate position effects, the latter still represent an introduction of added variance to the system reducing the power of the experiment to detect real treatment differences. In addition, in studies using pheromone traps to elucidate weevil distribution or to map movement on a fine scale, there is no alternative to adequate spacing. Our data indicate that a 20-m spacing is too close in such situations. Further experimentation will be necessary to determine how far apart is far enough, but in the interim, it seems prudent to maintain trap distances of at least 30 m.

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